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SPATS: A Model for Projecting Softwood Timber Inventories in the Southern United States

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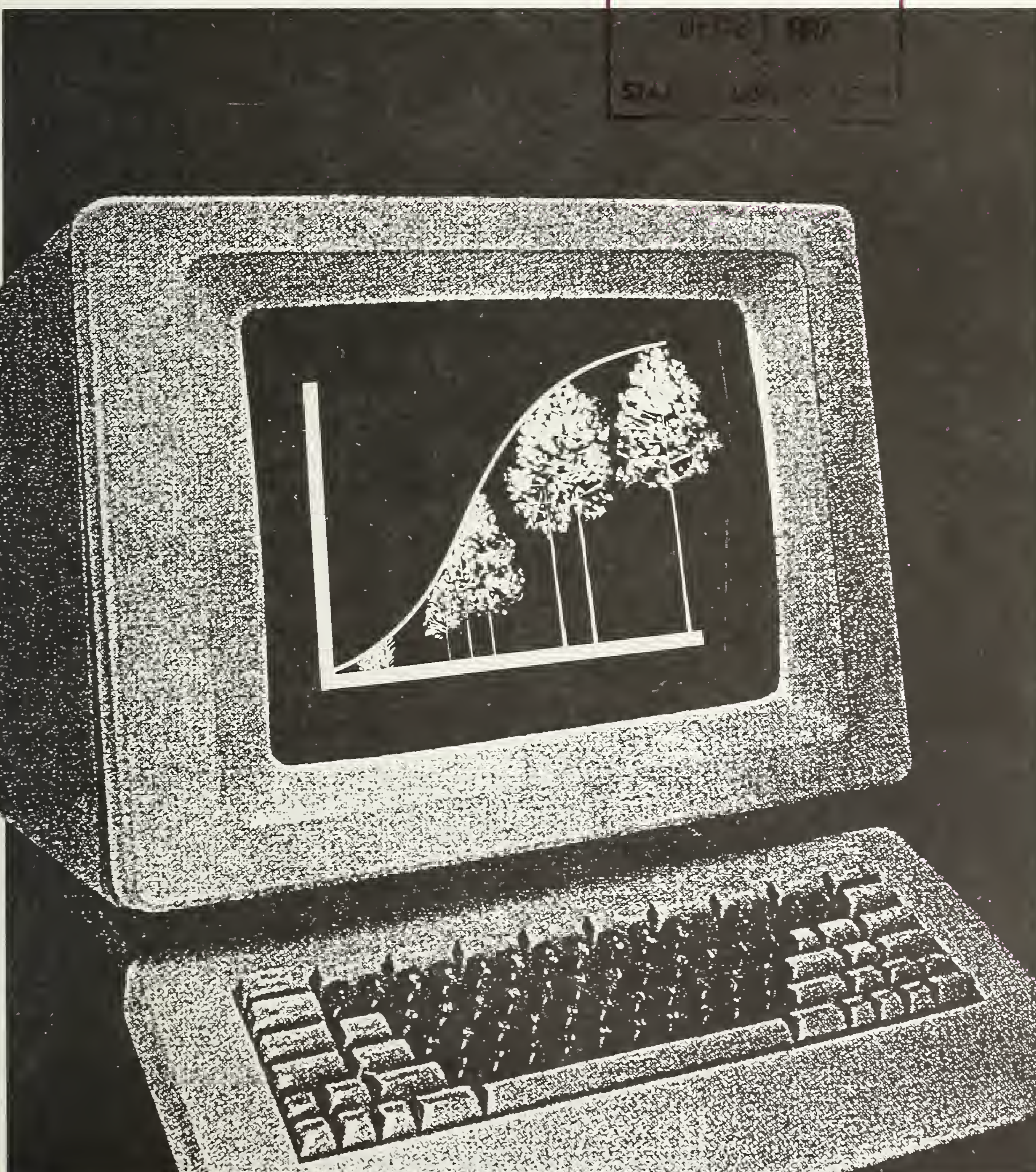

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Abstract

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The yield-table projection method for modeling the development of regional timber inventories is outlined, and its application to softwood timber types in the Southern United States is described. Problems of simulating forest management practices and natural succession are discussed. A computer model that projects softwood timber inventories using yield-table projection and stand regeneration using a Markovian probability structure is presented. The methodology and projections of this model are compared with alternative approaches to predicting future timber inventories in this region.

Keywords: Yield-table projection, inventory models, softwood timber supply, South.

Research Summary

Simulating the development of regional forests is an essential component of long-term timber supply studies. The Southern Pine Age-class Timber Simulator (SPATS) was designed to be used in conjunction with a model of North American timber markets. The SPATS model can also be used as a “stand-alone” simulator of softwood forests in the Southern United States.

Yield-table projection is an approach to timber inventory modeling in which forest area and yield are represented by stand age and other characteristics. Among the forest characteristics identified are management regimes that include stand origin and harvest age. Yield-table projection is essentially an elaborate bookkeeping framework in which biological and human processes are simulated with sets of rules for removing, shifting, and replacing area cells in the initial distribution. These rules are summarized as sets of equations.

Two types of model validation are discussed. In one, the model structure is examined to ensure that the pieces are complete and correctly assembled. In a second type of validation, model output is examined and, if possible, compared with actual results. In long-term projection models, only the first type of validation is possible.

Comparing projections made by different models, with similar input data, is useful, however. Therefore, the SPATS model is compared to another timber resource inventory model. Projections made by use of these models are similar. Although this comparison cannot be considered a validation of either model, it does provide useful insights. One important result is the implication that projection models can be operated with a greater degree of data aggregation when critical model routines rely on simple proportionality assumptions.

Information on operating SPATS, a description of the stationary Markov regeneration model, a table of model variable definitions, and sample data files are included as appendixes.

Contents

Introduction

Modeling the development of regional forests is a macroanalytical complement of modeling individual stand or forest growth and yield. Macroanalysis of forest resource development emphasizes aggregate measures of resource conditions, such as total timber growing stock, the balance of net growth and drain, and broad categories of forest management. The outlook of regional projection models is commonly long term (50 or more years).

Two methods are commonly used to model timber inventories of large regions; these are stand-table projection and yield-table projection. Stand-table projection uses a frequency distribution of the number of trees (per unit area) arrayed by diameter class. Projections are produced by adjusting this distribution based on diameter growth and tree mortality (including harvest). Yield-table projection, used in the model reported here, uses a classification of the regional forest according to age groups and additional stand characteristics. A third projection method, based on the simulation of individual tree growth, has had limited application in long-term projection for large areas. Alig and others (1984) review timber inventory projection methodologies and specific models in some detail.

Computer models that simulate forest resource development can be further classified as either descriptive or optimizing. For descriptive models, output is interpreted as a conditional projection of future conditions, given that critical variables are at their assumed values over the projection period. The input data and assumptions of the model are intended to reflect "most likely" behavior under different sets of assumptions. In contrast, optimizing models are characterized by the use of an objective function that is either maximized or minimized, thereby yielding values of the critical decision variables. Optimizing models project resource development conditioned on behavior following a computed optimal path. Descriptive models use explicit assumptions about the values of these decision variables to generate the predicted values of the model system.

This report documents a computer model that was developed to provide descriptive projections of future softwood timber inventories in the Southern United States. The Southern Pine Age-class Timber Simulator, SPATS, was designed to support an analysis of public policy targeting nonindustrial private owners (Brooks 1985). This policy analysis linked SPATS with TAMM, the Timber Assessment Market Model (Adams and Haynes 1980), a market- simulating, spatial equilibrium model of North American softwood timber and product markets. A model of economic behavior in timber markets (such as TAMM) and a model of timber inventory development together provide an opportunity to examine the interaction of the supply and demand for timber in both the long term and the short term.

Background

At the time SPATS was developed (1981), the computer model used by the USDA Forest Service to make long-term timber inventory projections was the Timber Resource Analysis System (TRAS) (Larson and Goforth 1974). Simulations of the development of North American timber markets using the Timber Assessment Market Model, in which TRAS is incorporated, are described by Adams and Haynes (1980).

The TRAS model has two major shortcomings when it is used for long-term projections of inventory development. First, incorporating into TRAS data sets assumptions about future forest management activity is difficult, and it is both more important and more difficult when future management is assumed to be significantly different from historical management. Adams and others (1982) describe simulations, using TRAS, of intensive forest management that required considerable artistry and program modification.

The second shortcoming is the implicit assumption in TRAS that the stand-type composition of modeled forests will remain unchanged. This assumption fails to take into account changes resulting from increased forest management (plantation establishment, for example), or changes that are the result of natural succession toward climax forest types. With these limitations, TRAS was not suitable for use in the study for which SPATS was developed, and doubts were raised about the reliability of TRAS-based projections of timber inventories for the South.[1]

Brooks (1985) used SPATS to develop a view of the future of southern forests in contrast to that provided by TRAS projections, and to examine the impact of alternative policy and planting strategies on this future. Since that study was completed, some developments require a revision to the presentation of the SPATS model but do not eliminate its relevance or its usefulness.

First, and most important, was the development of the Timber Resource Inventory Model (TRIM) (Tedder and others 1987). Like SPATS, TRIM is a yield-table projection model; however, TRIM has much more in common with the Timber Resource Economic Evaluation System (TREES) (Tedder and others 1980). The TRIM model was designed to represent forests of either large or small areas in any region of the United States, using forest survey plot data with flexible (user-determined) aggregation schemes. The SPATS model was designed to model only the private forests of the Southern United States, and although the data for SPATS are also derived from forest survey plot data, they are aggregated outside the model. The objectives underlying the development of SPATS were more focused and modest.

A second event, taking place at the same time that TRIM was being developed, was the undertaking of a comprehensive review of the present and the likely future conditions of southern forests. Because the TRAS-based projections had potentially serious biases, a review committee that collected additional data was formed. This committee conducted a broad review of assumptions about the future management of forests in the South and the demand for forest products (USDA Forest Service 1987); the TRIM model was used to develop resource projections for this study.

The relevance of these developments to SPATS, and to this document, is that a comparison of SPATS to TRAS is no longer necessary, nor particularly meaningful,

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[1] For example, compare projections in USDA Forest Service (1982) and the discussion in Boyce and Knight (1979).

in spite of the fact that TRAS-based projections dominate the literature (USDA Forest Service 1982). Five years ago it was necessary to make a case for an alternative view of the future of southern forests, based on the projections of a yield-table model; however, the usefulness of a yield-table model for projecting the development of the softwood forests of the Southern United States is now generally accepted. Therefore, analysts and policymakers must consider questions about the appropriate features of yield-table models. In this context, a comparison between SPATS and TRIM may be useful.

The remainder of this report contains a description of the yield- table projection methodology, an outline of the algorithm used in SPATS, and a discussion of model validation in which projections using SPATS and TRIM are compared. Further documentation of the SPATS computer program is in the appendixes.

Yield-Table Projection

Yield-table projection is a relatively simple, but versatile, approach to timber inventory projection. The forest is represented by a matrix that describes the distribution of forest area by age class and additional stand descriptors. These descriptors may include stand type, site class, stocking level, and management regime. Noncontiguous areas with identical descriptors are grouped for projection purposes.

Timber yields (per unit area) must be specified with the same descriptors as the area data. The product of the area matrix and yield matrix, summed over all age and type classes, is the total timber volume of the forest. In a yield-table model, the process of inventory projection is reduced to a bookkeeping problem: keeping track of the distribution of acres as they advance through age classes, are harvested, and (perhaps) change type descriptors, through time.

Forest management activity can be simulated in the yield-table framework by using the type descriptor to identify stands subject to different management regimes, as well as stands with different species composition. These regimes can include stand origin, intermediate treatments, and final harvest age. In yield-table projection models, harvesting is typically assumed to be based on even-aged management, although a more diverse approach to stand management can be represented. The assumption of even-aged management is embedded in the use of a single age class (usually the oldest available) for final harvesting. The representation of partial cutting in stands of a wide range of ages is especially difficult to represent in highly aggregated yield-table models.

The amount of model detail that is required to adequately represent the forest of a region is a function of the biological characteristics of the forest, the nature of management activity, and the purposes for which the projection is done. In principle, the representation of any set of management practices can be accomplished by expanding the type dimension of the yield-table model, with each type category representing a different management regime; however, there are practical problems that discourage unlimited expansion of this kind. As the basic dimensions of the model are expanded, there must be a concomitant expansion of associated data and model routines.

In the absence of data, assumptions must be made. In practice, model detail is often achieved, or at least supported, by means of broad assumptions or simple assertions.

The amount of detail in a regional inventory model should also be consistent with the relative importance of the details to model projections. In this context, the use to which the inventory model projections wili be put must be kept in mind. When SPATS was developed, for example, this was a matter of identifying the features of southern forests that are most subject to change, and for which changes will alter projections of long-term timber supplies. Long-term market projections made with TAMM use annual estimates of total regional growing stock (by owner) to shift short-term, private, timber supply functions. Therefore the magnitude of the potential effect on growing stock was used as a measure of the importance of particular model features.

The Southern Pine Age-Class Timber Simulator

The basic bookkeeping algorithm of the SPATS model can be summarized in general terms as:

$$A_{j,k,t+1} = A_{j-1,kt} - H_{j-1,kt}, \text{ for } 2 < j < J; \tag{1}$$

$$A_{J,k,t+1} = (A_{Jkt} - H_{Jkt}) + (A_{J-1,kt} - H_{J-1,kt}); \text{ and} \tag{2}$$

$$H_{jkt} = R_{jkt} / y_{jkt}; \tag{3}$$

where, subscript t indicates the period (the age class interval is 5 years); j is the age class (J indicates the oldest age class), and k is the stand type descriptor; A_{jkt} is the area in stands of type k, age class j at time t; H_{jkt} is the area of these stands harvested in time t; R_{jkt} is the volume harvested; and y_{jkt} is the yield per unit area. Twenty 5-year age classes are used in SPATS (the 0 age class indicates nonstocked acres); four stand types are modeled: natural pine, plantation pine, oak-pine, and hardwood.

Equations (1–2) advance the forest through age classes after accounting for harvest in the current period. In equation (1), the area in an age class in any period is defined as the area in the next youngest age class in the previous period, less the area harvested from the younger age class. Equation (2) treats the special case of the oldest age class, J. This age class contains any stands of this age class uncut in the previous period (the first expression), plus the uncut stands that were in age class J-1 in the previous period. The oldest age class is defined as an accumulating class; that is, it represents the area in stands at or older than a nominal maximum age.

Total harvest volume is determined exogenously and is converted to area (by age class) in equation (3). The distribution of harvest volume across type and age classes (R_{jkt}) is determined by simple proportionality assumptions, in the absence of better information. Harvest by type class is calculated by assuming that it occurs in proportion to the total eligible (merchantable) volume in each type. A similar rule is used to distribute harvest among age classes; harvesting begins with the oldest stand in each type, and any residual harvest request is taken from the remaining eligible age classes in proportion to the existing volume until the total request (for the type) is satisfied.

Where sufficient data exist, the simplistic proportionality assumption for distributing harvest by age class should be modified. Some yield-table models include an option for the user to specify the proportion of harvest to be taken from each age class. Unfortunately, information on the age-distribution of harvest is seldom available for large areas; as a result, the harvest rule used most often in yield-table models is "oldest first." With this approach, harvesting begins in the oldest age class, removing the entire area in each class (if necessary) before moving to the next youngest class. The drawback of this rule is that it imposes a crude form of area regulation that is not typical of existing stands.

A long-term inventory projection model must account for the changes in regional forests brought about through forest management and natural succession (forest dynamics). One of the most important aspects of forest dynamics is new stand establishment after harvest. In SPATS, new stands are separated into two classes: stands regenerating naturally (that is, the new stand type after harvest is determined by conditions on the site, without human intervention) and stands regenerated as an act of forest management. In equation (4), natural regeneration (N_t) is defined as a residual: the total area harvested, less the area actively (artificially) regenerated (P_t).

$$N_t = \left(\sum_j \sum_k H_{jkt}\right) - P_t \, . \tag{4}$$

Because the distribution of planting across (source) stand types is not known, N_t is a scalar (it has no type dimension). In equation (5), the type dimension for natural regeneration is estimated from weights derived from the distribution of harvest by stand type.

$$N_{kt} = \left(\sum_j H_{jkt} \Big/ \sum_k \sum_j H_{jkt}\right) N_t \, . \tag{5}$$

A different probabilistic structure is required for modeling artificial regeneration. Artificial regeneration (plantation establishment) is the primary forest management activity in SPATS because it reflects the predominant importance of planting in determining the character of the future forest in the South. In addition, public policy frequently focuses on planting by private owners in the South as an instrument for accomplishing long-term supply objectives; therefore, the model user must specify the level of planting for each period.[2] The probability is nonzero that some plantations will fail, however. The area of attempted plantations is deterministic and is an explicit element for policy analysis in SPATS; the results of this management effort are probabilistic.

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[2] Three options are used in determining the area planted in each period: a user-specified annual rate for each period, planting set equal to the area harvested, and planting computed from regression-derived equations. See Brooks (1985) for an example of the use of this last option.

The complete regeneration process in SPATS can be summarized:

$$A^n_{kt} = N_{kt}\, T_{(k \times k)} \; ; \tag{6}$$

$$A^a_{kt} = P_t\, \Pi_{(1 \times k)} \; ; \text{ and} \tag{7}$$

$$A_{1,k,t+1} = A^n_{kt} + A^a_{kt} \, . \tag{8}$$

Equations (6-7) calculate the area entering the first age class by both natural and artificial means. Natural regeneration is computed in equation (6) from a Markov-type transition matrix, T, in which the probability of an acre regenerating into any type is conditioned on the type in existence at the time of harvest. The product of the (1 x k) vector N_{kt} and the (k x k) matrix T is a (1 x k) vector showing the area regenerating naturally into the first age class of each type. A brief description of the Markov process, as applied here, is in appendix 2.

In equation (7), a (1 x k) plantation outcome probability vector, Π, is used to calculate the area entering the first age class of each type as a consequence of plantation effort. In general, most efforts to establish plantations are successful for any owner; the range of "failed" outcomes includes no stand and stands of other type classes (indistinguishable from those of natural origin). Equation (8) is a simple summation that completes the assignment of acres to the first age class.

In equation (3), timber yields are shown to have a time index, as well as age and forest type dimensions; this reflects the expectation that average yields will change over time, demonstrating an "approach to normality." That is, to the extent that yields in time t (for any age and type class) are based on stands with other-than-normal stocking, the yields of these stands are expected to become more "normal" over time. In general, the direction of this approach is from below (in aggregate, forests tend to be understocked), although the principle applies as well to stands with higher than normal stocking. This change in yield is the product of a natural process (stands tend to fully occupy sites); at the same time, it also reflects changes in management practices not modeled explicitly. In both cases, yields must be adjusted over the projection period.

The starting point is a vector of area-weighted average volumes per acre (by age class) for each forest type: y_{jkt}, for t=0. The product of these yield vectors and the initial area vectors (A_{jkt}), summed across all forest types, is the total growing stock at the start of the simulation. Yields are adjusted by assuming that the approach to normality proceeds at a decreasing rate toward a bound. The relationship is

$$p_{jk,t+1} = \alpha_0 + \alpha_1\, p_{jkt} \; ; \tag{9}$$

where p_{jkt} indicates the yield in time t for stands of age j, type k, expressed as a proportion of normal yields, and α_0, α_1 are parameters of the approach to normality

function. The upper bound (the maximum proportion of normal) for any stand is defined by $\alpha_0/(1-\alpha_1)$. Yields for each period are calculated as

$$y_{jkt} = y^n_{jk} p_{jkt} ; \tag{10}$$

where y^n_{jk} is the normal yield for age j of type k. The proportion of normal is roughly equivalent to an area-weighted, average stocking level for the type class. In SPATS, the proportion of normal at the start of the simulation is constant for all age classes; program options allow the user to specify different rates of change for stands in different age groups (for example, a less rapid approach—or none at all—for older stands).

Two points are important here: first, the proportion of normal at the start of the simulation must reflect actual conditions. This is essentially a matter of model calibration. It can be seen that this calibration can be done with any two of the three pieces of information in equation (10): (a) empirical yields (y_{jkt} for t=0) that, in conjunction with the area distribution, produce the known initial volume; (b) normal yields for the forest type (y^n_{jk}); and (c) an estimate of the proportion of normal (the stocking percent) at the start of the simulation. Empirical yields (average volumes per acre) are available as part of the basic inventory data; p_{jk0} can be estimated from empirical stocking data. Alternatively, normal yields can be specified and p_{jk0} computed as the ratio of empirical and normal yields.

Second, the approach to normality equation must be reasonable in terms of both the rate of approach and the maximum proportion achieved (the upper bound). This is mainly a matter of sensitivity analysis and user judgment because little empirical information concerning the approach to normality is available. (An exception is Chaiken (1939), who estimated that undisturbed (average) loblolly pine stands in the South will increase in stocking 12.5 percent over a 5-year period.) This, too, is a model feature through which users can incorporate assumptions about the yield impact of future management actions not explicitly modeled (the use of genetically improved stock, for example).

Model Validation

Two types of model validation can be considered: structural and empirical. Structural validation appeals to sources that support the form of the model, without reference to specific results (model output). Empirical validation, on the other hand, compares model output to data from alternative sources.

Yield-table projection is a familiar and simple methodology, and no further effort will be made to defend its use as a structure for projecting regional timber inventories. The SPATS model also has structural features in common with forest succession models. By a taxonomy developed by Shugart and West (1980), SPATS can be described as a forest succession model composed of a mosaic of elements, each representing stands of a given age and forest type (and management regime). Unlike most forest succession models, however, changes in this mosaic in SPATS are modeled as being neither purely probabilistic nor simply continuous.

The literature contains examples of forest models that simulate forest succession but do not incorporate human-caused "disturbances" (Shugart and others 1973); succession in this case is a continuous process. Using a probability matrix, Usher (1966) develops a forest model (in which harvesting is recognized), but it is applied only to the problem of determining sustained yield in uneven-aged forests. Aging in SPATS is a continuous process up to the time of harvest; the timing and the extent of the removal of older stands are determined by a model of human (economic) behavior or by assumption, independent of the model of the forest. New stand establishment is mainly, but not entirely, probabilistic. In this combination of natural and human-dependent relations, the structure of SPATS more closely represents the conditions of southern forest development over a long period.

It is impossible to provide empirical validation for a long-term projection model; the model provides estimates of future values that cannot be known. Projections, too, are conditioned on the values of parameters and input data; any evaluation is simultaneously a test of model structure and data. A partial substitute for full-scale empirical validation is provided by starting the simulation at a point as far before the present as data permit; model output can then be compared to historical data. Conceptually, this is the most appealing form of validation; unfortunately, little historical data with which it can be done are available. The basic input data for SPATS are available only for one point in time; historical validation requires equivalent data sets for (at least) one full projection cycle (5 years). Although this type of validation is not possible now, in the future it will be available.

Another kind of validation compares projections made by independently developed models with comparable data sets. Neither model can provide a "more correct" view of the future, but independent forecasts should be consistent. This process is both a structural and an empirical validation, and it is in this context that a comparison of SPATS and TRIM is useful.

Both SPATS and TRIM are yield-table projection models, but they differ in several important respects. Not the least of these differences is the amount of detail used to represent the forests of the region. A bigger model (one with more detail—TRIM in this case) is commonly assumed to produce more reliable results; however, this assumption is seldom subjected to an empirical test. The choice between large and small models should be based on a direct comparison of model characteristics and results; it can be argued (based on Occam's principle, if no other) that the simpler model should be used if there is little or no difference in the value of critical variable(s) projected by the models.[3] Perhaps the most valuable benefit from a comparison of SPATS and TRIM is the opportunity to evaluate the impact of data aggregation (or disaggregation) on timber inventory projections for the Southern United States.

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[3] Occam's principle (*"essentia non sunt multiplicanda praeter necessitatem"*) is equivalent to the engineering principle: begin with the simplest approximation, and add new features only as necessary.

Other differences between SPATS and TRIM include the manner in which stands are harvested and assumed to regenerate, and the way in which changes in the forest land base are modeled. In TRIM, the "oldest first" harvesting rule is used, and all harvested stands are assigned initially to the original stand type. In each period, stands (of any age) are subsequently shifted between classes that include both forest type and management intensity. These shifts are user-specified and, in principle, can be made to be equivalent (in results) to the transition probability framework in SPATS. Changes in the forest land base in TRIM are treated similarly; any additions or deletions are accounted for through user-directed shifts. Tedder and others (1987) describe this process in more detail.

In spite of these differences, the models are similar in most other respects, and it is reasonable to compare their output. With equivalent data sets and assumptions, projections of broad aggregates (total growing stock, for example) by the two models should differ very little. Data for SPATS were taken from TRIM basic resource unit files and aggregated. Site classes, stocking levels, and management intensities were combined in area data; empirical yields were calculated as area-weighted averages. Removals from growing stock (specified by owner and region) are identical in the two simulations; data shown in TRIM allowable cut unit (softwood) reports were used in the SPATS projection.[4] Planting is prespecified in the SPATS projection; actual data for 1980-84 are used, and in subsequent periods data are based on trends from the 1980-84 average.

Projected values for softwood growing stock are shown in figure 1; projected values for softwood growth are shown in figure 2. Projections are shown for two owners (forest industry and nonindustrial private) in each of two regions (Southeast and South Central). In three of four projections, the SPATS projections closely track those made with TRIM. The maximum difference in projected growing stock in any year in these three projections is less than 10 percent. The exception to this close tracking is the South Central forest industry where SPATS projects a rapid increase in growing stock after the year 2000. The TRIM projection for the South Central forest industry is somewhat puzzling, especially when compared with the TRIM projection for forest industry in the Southeast. Over the period 1975-84, forest industry owners in the South Central region established pine plantations at a faster rate than their counterparts in the Southeast. The SPATS projection of growing stock eventually reflects this activity, but the TRIM projection apparently does not. Projected values for softwood growth are also close, again with the exception of the South Central forest industry.

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[4] The TRIM data are from unpublished output titled "Run 17 SO Base Round 3" and dated 86/07/18; reports on file at the Macroeconomics of U.S. and International Trade Project, USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon.

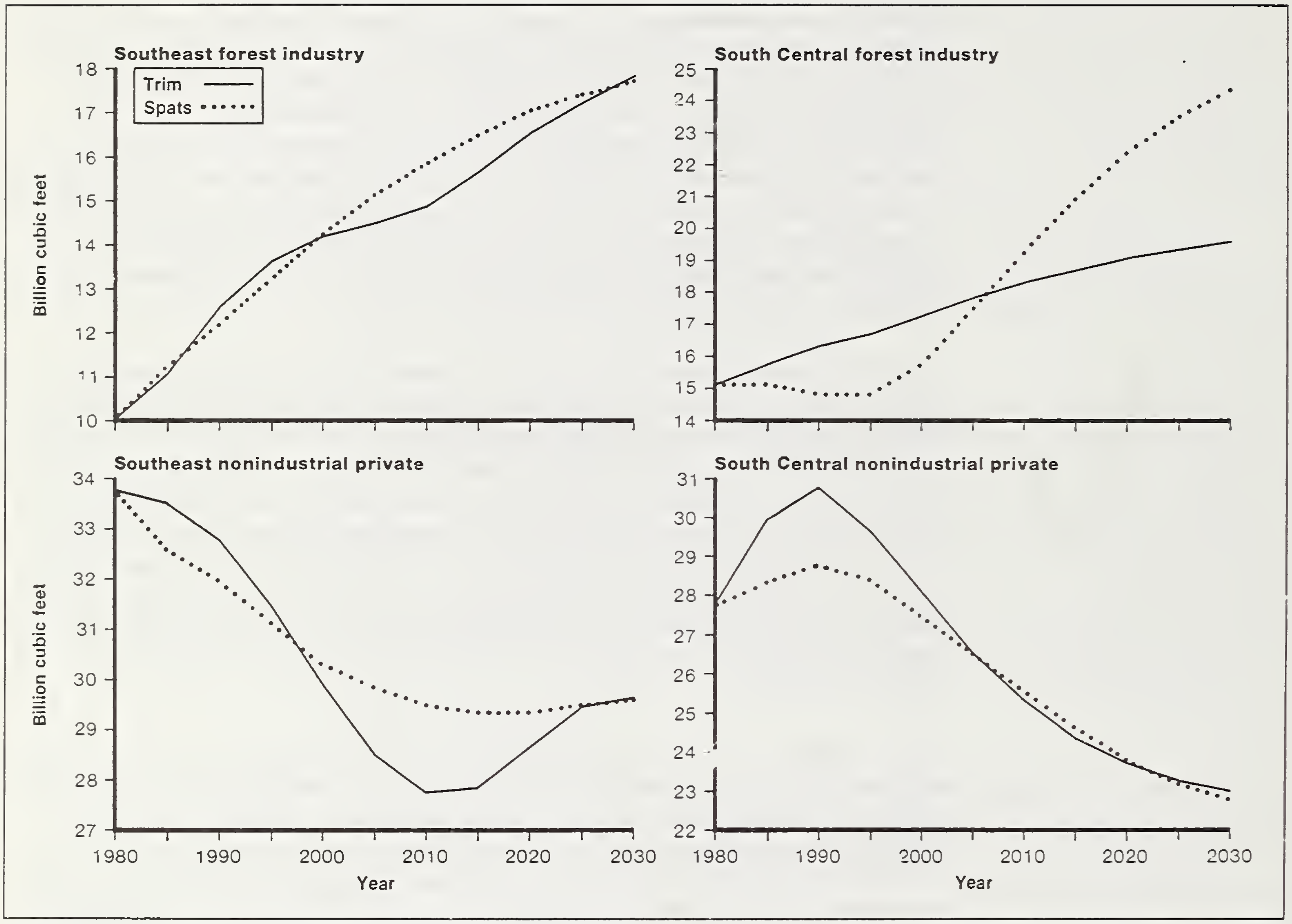

Figure 1—Projections of softwood growing stock by region and owner, 1980 to 2030, made by TRIM and SPATS.

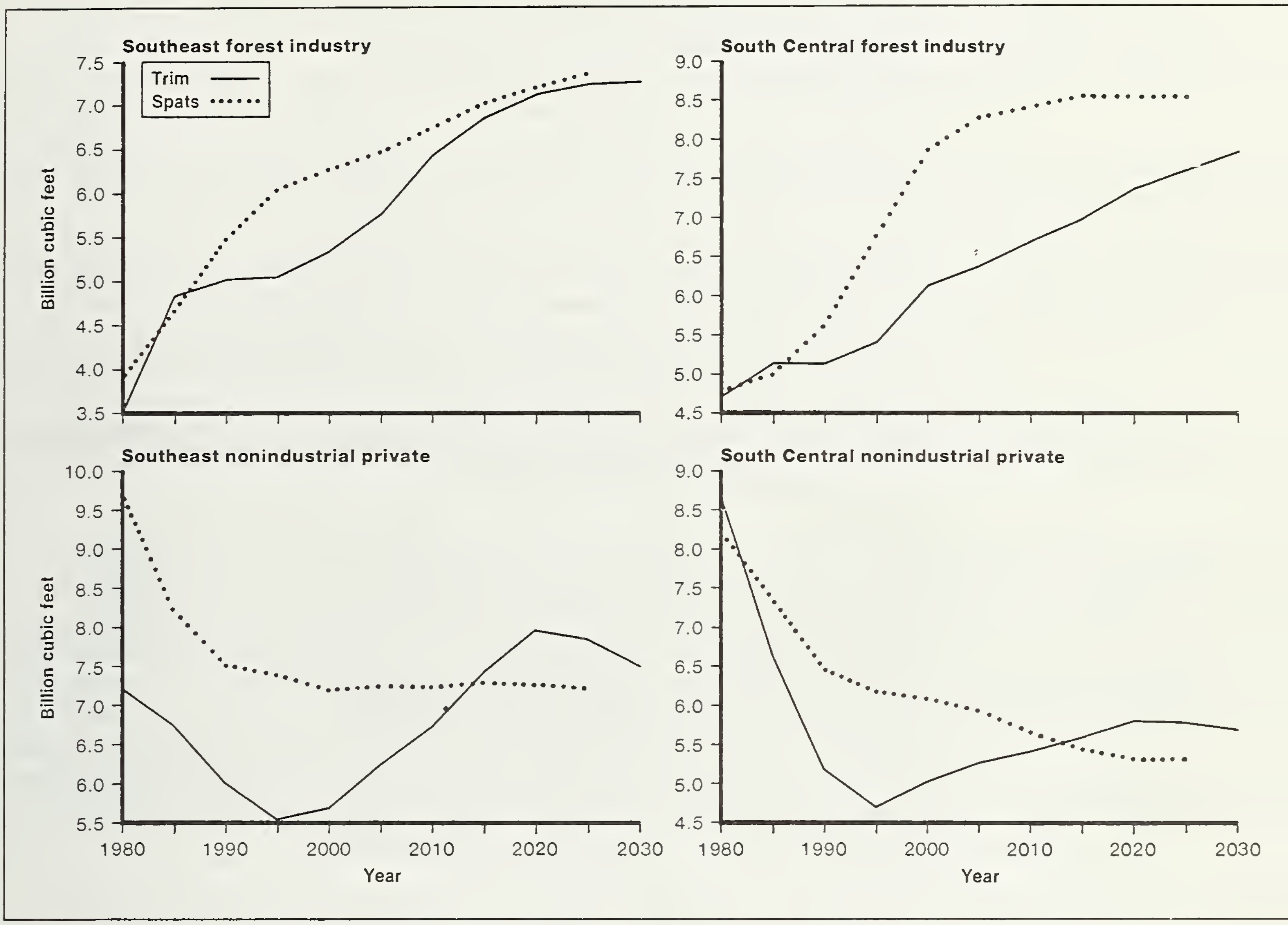

Figure 2—Projections of periodic softwood growth by region and owner, 1980 to 2030, made by TRIM and SPATS.

Theil's (1966) inequality coefficient was computed for each pair of simulations by assuming that the TRIM projections of softwood growing stock are the "actual" data, and the SPATS projections are the predicted data. A value of zero indicates a perfect fit; a value of 1 can be obtained by predicting a constant value. Results are shown in table 1. The sources of the forecast error are also shown as proportions of the total error. The quantitative measures shown in table 1 confirm the graphic comparisons in figure 1.

To conclude from this comparison that one model is more "correct" than the other (or, because of the similarity, that both are correct) is not appropriate. Nevertheless, that these two models, using similar but not identical assumptions, and organized quite differently, come to similar conclusions about the time path of softwood growing stock for private owners in the South, is somewhat reassuring. With the exception of the South Central forest industry, differences between growing stock projections produced by SPATS and those produced by TRIM will have very little impact on estimates of short-term timber supply in TAMM.

Some inferences can be drawn about data aggregation and model simplicity from these results. The SPATS projections are similar to those from TRIM in large part because the extensive detail in TRIM is the result of (or at least is supported by) simple proportionality assumptions. For example, although there are sufficient data to classify forest area in TRIM by forest type, site class, stocking level, and management intensity, little if anything is known about the distribution of harvest across these dimensions of the forest. Therefore, harvest is assumed to be proportional to the area or volume in each dimension. Under these circumstances, however, to use aggregated area data and weighted average yield data is algebraically equivalent; as a result, SPATS projections are similar to those produced by TRIM.

In some applications, the extensive detail contained in TRIM is desirable, if not required. That TRIM is flexible in terms of the detail it maintains is also important to keep

Table 1—Comparison of TRIM and SPATS projections of softwood growing stock, by use of Theil's inequality coefficient

Region and owner	Inequality coefficient	Sources of forecast error[1/]		
		Bias	Variance	Covariance
Southeast:				
Forest industry	0.4249	0.0013	0.0208	0.9779
Nonindustrial private	0.6660	0.0000	0.3900	0.6100
South Central:				
Forest industry	1.9585	0.2659	0.4121	0.3220
Nonindustrial private	0.5298	0.0014	0.7058	0.2928

[1/] Expressed as a proportion of the total error.

in mind. In fact, aggregation procedures for TRIM that will result in an inventory structure similar to that used in SPATS can be defined. In some applications, however, the detail that TRIM is able to provide seems to be of little benefit; for example, long-term timber market simulations made in conjunction with TAMM.

Timber inventory model size and data requirements must be kept proportional to their relative importance; however, the development of regional inventory models should not be arrested at the complexity of SPATS. As data improve, more detailed models will be able to provide more robust projections. The argument made here, and supported to some extent by the direct comparison of SPATS and TRIM, is for a careful assessment of the question of appropriate scale and the amount of detail to include in regional timber inventory simulation models.

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Appendix 1
Operation Notes

Spats was written in the American National Standards Institute (ANSI) standard FORTRAN-77 language; it has been compiled and executed on a Control Data Corporation (CDC) Cyber 170/720 mainframe computer, and on IBM-PC-compatible microcomputers.[1] Source code and sample data sets are available from David J. Brooks, P.O. Box 3890, Portland, Oregon 97208. The SPATS model contains 10 subroutines and a program segment; when SPATS is used in conjunction with TAMM, the program segment is replaced by subroutine calls within the main control segment of TAMM. Subroutine names are shown in table 2, along with a brief description of subroutine operations. Figure 3 illustrates the sequence of operations in SPATS and the flow of information between SPATS and TAMM. The SPATS model can also be operated as a "stand-alone" model; in this case, annual removals data must be provided as an additional data file.

Two output files are created by SPATS. The primary output file is titled "SPATOUT" and is addressed as unit 12. This file contains simulation summary tables (always produced) and any other program output selected by the user (table 3). Output file "ANNUAL" (unit 7) contains a one-line report for each owner, in each year of the simulation. This file can be sorted to produce a time series of annual estimates of growing stock for each owner.

Program output options (included as data items in input file TAPE1) are shown in table 3. This table also includes information on user options for setting the manner in which plantation establishment is determined.

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[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Table 2—Subroutines in SPATS

Subroutine	Operation
SPTSIN	Data input, reads from file TAPE1.
SPTSGD	Growth-drain model, estimates annual change in growing stock; calls SPATS every 5th year.
SPATS	Control for the "full model"; calculates periodic yields; calls all remaining subroutines (except SPTSUM) in sequence.
ACHNG	Calculates area change.
REMOVE	Computes net removals of growing stock, given timber supply.
HRVPV	Thins and harvests the forest; final harvest is proportional to volume.
LEASE	Thins and harvests leased land.
REGROW	Regenerates and grows the forest.
VOLCAL	Computes area and volume statistics.
SPTSUM	Writes simulation summary tables; called from TAMM, or emulator.

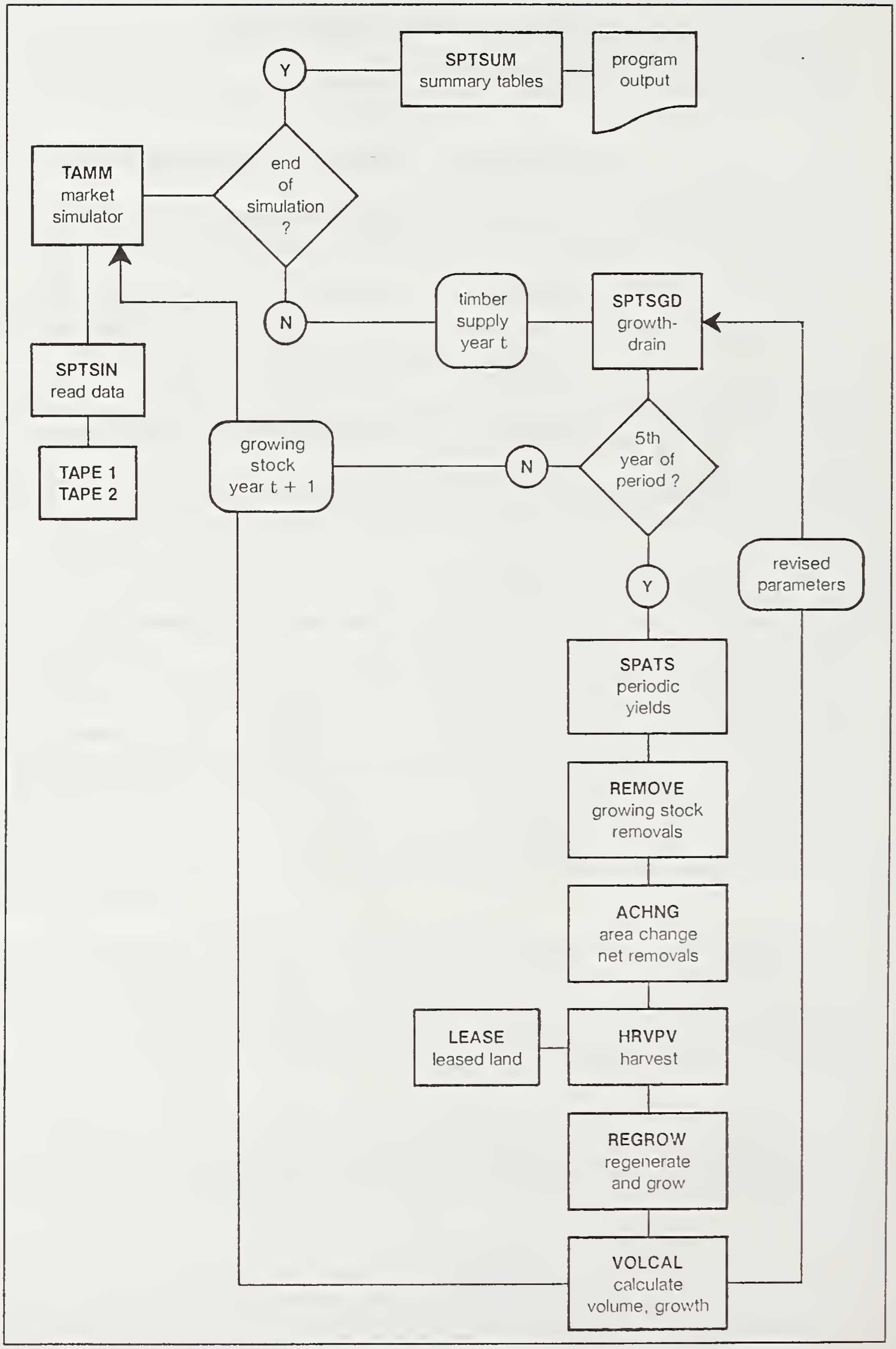

Figure 3—Sequence of operations and flow of information in SPATS.

Table 3—SPATS output options

Variable	Value	Result
IPRINT	0	Short form of output, summary tables only
	1	Full report in every period
IWRITE	0	No echo of input data
	1	Echo input data
IPLANT	0	Planting prespecified, read as ACRPLT(I)
	1	Planting computed from response equations
	2	Planting set equal to annual harvest

Appendix 2
The Stationary Markov Regeneration Model

The forest is characterized by stands of 1,...,K different forest types (where K indicates the total number of types represented). When stands of any type (k) are harvested in time t and allowed to regenerate naturally, they can remain in type k or change to one of the other types. The probability that a stand harvested from type k will regenerate as type m (where m may equal k) is defined as ν_{km}. This is a stationary transition process if ν_{km} does not change over time. The process is also said to be Markovian if this transition probability does not depend on the path by which the stand reached type k.

These transition probabilities have the following additional properties:

$$\nu_{km} \geq 0 \quad \text{for all k,m; and} \tag{11}$$

$$\sum_{m} \nu_{km} = 1 \quad \text{for all k.} \tag{12}$$

The matrix T in equation (6) is composed of the elements ν_{km}; equation (11) states that all elements are nonnegative, and equation (12) that the rows of T sum to one.

Forest types in SPATS are states in a finite-state Markov system. Ordinarily in such a system, the n-step transition probability can be computed by (n) successive squarings of the transition matrix. Because of the properties stated in equations (11-12), the consequence of this self-multiplication is that the row vectors converge to values that define the steady-state condition for the system.

In the natural regeneration transition matrix defined here, however, the system is incomplete, and the n-step transition probability that results from this computation is not valid. Consider, for example, the transition probability matrix in table 4. This is an expansion of data shown in appendix 4 (the rows added for hardwood and non-stocked create a square matrix). The "steady-state" probabilities that result from successive squaring of this matrix are also shown in table 4.

Table 4—Natural regeneration transition probabilities and "steady-state" probabilities

Source	Destination				
	Pine[1]		Oak-pine	Hardwood	Nonstocked[2]
	Natural	Plantation			
Pine:[1]					
Natural	0.40	0.0	0.25	0.30	0.05
Plantation	0.30	0.0	0.35	0.30	0.05
Oak-pine	0.05	0.0	0.15	0.80	0.0
Hardwood	0.0	0.0	0.10	0.90	0.0
Nonstocked	0.0	0.0	0.05	0.05	0.90
Steady-state probabilities[3]	0.0089	0.0	0.1064	0.8803	0.0044

[1] Natural = pine stands of natural origin; plantation = planted stands.

[2] Source stand type identity is retained.

[3] Convergence was reached after 7 transition steps.

This regeneration system is incomplete because pine plantations are introduced into the system in each period through artificial regeneration, and stands of all types are candidates for planting. When plantations are harvested, if they are allowed to regenerate naturally, they will follow the transition paths indicated in table 4. The probability, however, that stands in any type will regenerate to plantations depends on management decisions. In the probability structure shown in table 4, plantation establishment is deterministic, although it is "passed through" a separate probability framework (shown in table 5).

Table 5—Plantation outcome probabilities[1]

Owner group	Stand type resulting from planting				
	Pine[2]		Oak-pine	Hardwood	Nonstocked
	Natural	Plantation			
Forest industry	0.096	0.800	0.089	0.0	0.015
Nonindustrial private	0.097	0.700	0.156	0.0	0.047

[1] Data are from appendix 4.

[2] Natural = pine stands with yields equivalent to those of natural origin; plantation = successful plantations.

Appendix 3
Description of Variables

A partial dictionary of variables used in SPATS follows; included are all items contained in the two data files that must be created by the user. No owner index is indicated for any variable; data for each owner are stored in direct access files with records identified by region and owner indexes. Annotated sample data files are shown in appendix 4.

Variable name	Description
ACRE(J,K)	Softwood forest area by age (J=0,19) and stand type (K=1,3)
ACRHD	Area of hardwood stands
ACRLS(J,K)	Area of forest land leased by forest industry (K=1,2)
ACRPLT(I)	Area planted in period I (I=1,11)
AVGSVH	Average softwood volume in hardwood stands
ANITCP	Intercept term for the approach to normality function
ANRM(I)	Proportion of normal yield in period I
ANSLOP	Slope term for the approach to normality function
AREALS	Total area leased by forest industry from nonindustrial
AREA0	Total (initial) forest area
BETA(36,8)	Array through which estimate of growing stock is passed to TAMM
BETAP(J)	Parameters for the planting response equation (J=0,5)
BFCF(J)	Board foot/cubic foot ratio, by age class (J=0,19)
BFCF0	Average board foot/cubic foot ratio
CFACT	Growth-drain, available cut adjustment factor (CFACT >0.20)
COMARA(I)	Total commercial forest land area at the end of period I
CRPIDL(I)	Idle cropland available for natural regeneration
GCRAT(0)	Startup value, growth/cut ratio
GPCNT0	Startup value, growth percent
GSINV0	Startup value, total softwood growing stock
GSMRCH0	Startup value, merchantable softwood growing stock
HARDLS	Hardwood forest type, area leased
HARDMIN	Minimum area of hardwood forest type
I	Index indicating the simulation period (5-year interval)
IPLANT	Flag indicating type of planting computation
IPRINT	Flag indicating output option
IWRITE	Flag indicating output option
ISTRT	Starting year for the simulation
J	Index indicating age class (J=0 is nonstocked)
JFULAP	Maximum age class for full approach to normality
JHLFAP	Maximum age class for half approach to normality
JMN(K)	Minimum harvest age, by softwood type
JMNT(K)	Minimum thinning age, by softwood type
JMX(K)	Maximum age class, by softwood type
K	Index indicating softwood forest type
L	Index indicating owner group
LAGEND	Flag indicating the use of lagged endogenous variables, planting equations
LAGPAY	Flag indicating the number of lags for public payments, planting equations
LAGX(N)	Flags indicating lags on right-hand-side variables, planting equations
LSMRCH0	Initial merchantable softwood volume, leased land
LSVOL0	Initial total softwood volume, leased land
NNPER	Number of periods in the simulation
NNREG	Index for region
NNUM	Index indicating the number of region-owners
NRGO	Index for owner group
OO	Unit number for primary output file (assumed to be 12)

Variable name	Description
OWNER	2-character identifier for owner group
PAI0	Initial periodic annual increment
PINE0	Initial area in softwood types
PLR(I)	Proportion of growing-stock removals left as logging residues in period I
POR(I)	Other removals of growing stock in period (proportion)
PPRG	Proportion of idle cropland regenerating each period
PPT(K)	Plantation outcome probabilities (K=1,4)
PRG(KS,KD)	Natural regeneration transition probabilities; KS(source type)= 1,3; KD (destination type)=1,5
PRNGS(I)	Proportion of roundwood taken from nongrowing-stock sources in period I
PRPM	Proportion of merchantable material used in area change
PTHYLD(J,K,I)	Thinning yields (area proportion times volume proportion) by age (J), stand type (K), and period (I)
REGION	2-character identifier for region
RNS(K)	Proportion of nonstocked acres regenerated, by softwood type
REMOVE(36,4)	Array through which removals are passed from TAMM to SPATS
STITLE	80-character data identifier
STAND0(K)	Initial area by stand type
SYLD(J,K)	Empirical yields, by age and softwood type (K=1,3)
SYLDN(J,K)	Normal yields, by age and softwood type
XVAR((J,I)	Right-hand-side variables for planting equations, by period

Appendix 4
Annotated Data Files

TAPE1 (unit 1)
TAPE1 contains all data except annual removals and is read at startup by subroutine SPTSIN. The general structure is:

N (the number of region-owner "blocks")
BLOCK 1 (Southeast forest industry)
BLOCK 2 (Southeast nonindustrial private)
BLOCK 3 (South Central forest industry)
BLOCK 4 (South Central nonindustrial private)

The ordering of the blocks does not matter as long as the indexes in each block are correct. Single-owner simulations can be made when leased acres are not explicit; otherwise, the simulation requires a pair of owners for each region: forest industry and nonindustrial private. Variable names and dimensions are shown in brackets [] for explanation. See appendix 3 for a brief description of the variables.

```
[NNUM]
4
[STITLE]
LR 46 REMOVALS / ALIG TOTAL AREA PROJECTIONS / TRIM AGE DATA /
[REGION, OWNER]
SEFI
[NNREG, NRGO, L]
10 1 1
[ISTRT, NNPER, OO, IPRINT, IPLANT, IWRITE]
1980 10 12 0 2 0
[(JMNT(K), JMN(K), JMX(K), K=1,3)]
3 5 19 3 5 11 6 8 19
```

[((ACRE(J, K),   K=1,3),   J=0,19)]

0.00	0.00	0.00
410.59	2018.70	322.17
179.66	1452.60	175.71
203.45	1006.48	128.06
386.03	1052.62	106.05
594.65	521.86	83.02
537.30	88.00	115.17
584.73	32.58	103.13
442.01	15.95	116.39
244.93	5.20	105.82
241.90	3.62	76.44
147.86	0.00	75.33
142.35	0.00	29.16
63.57	0.00	28.02
25.73	0.00	26.49
17.38	0.00	18.37
21.27	0.00	11.24
12.73	0.00	12.06
16.94	0.00	16.34
0.00	0.00	0.00

[ACRHD]

5678

[((ACRLS(J,K), J=0,19), K=1,2)]

0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

[HARDLS]

00.0

[((SYLD(J,K), J=0,19), K=1,3)]

.021	.156	.416	.676	.910	1.118	1.274	1.417	1.529	1.612
1.703	1.770	1.820	1.867	1.898	1.924	1.945	1.960	1.971	1.976
.031	.156	.364	.884	1.352	1.768	2.028	2.158	2.262	2.288
2.314	2.314	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
.052	.099	.130	.195	.293	.366	.435	.503	.567	.626
.680	.728	.772	.806	.834	.858	.876	.886	.889	.889

[AVGSVH]

.123

[((SYLDN(J,K), J=0,19), K=1,3)]

.040 .300 .800 1.300 1.750 2.150 2.450 2.725 2.940 3.100
3.275 3.405 3.500 3.590 3.650 3.700 3.740 3.770 3.790 3.800
.060 .300 .700 1.700 2.600 3.400 3.900 4.150 4.350 4.400
4.450 4.450 .00 .00 .00 .00 .00 .00 .00 .00
.100 .190 .250 .375 .564 .704 .837 .967 1.091 1.204
1.307 1.401 1.484 1.551 1.604 1.650 1.685 1.705 1.710 1.710

```
[(((PTHYLD(J,K,I), J=3,8), K=1,3), I=1,12)]
 .066 .066 .109 .0 .0 .0 .109 .124 .124 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .068 .111 .0 .0 .0 .109 .126 .126 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .070 .113 .0 .0 .0 .109 .128 .128 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .072 .115 .0 .0 .0 .109 .130 .130 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .074 .117 .0 .0 .0 .109 .132 .132 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .076 .119 .0 .0 .0 .109 .134 .134 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .078 .121 .0 .0 .0 .109 .136 .136 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .080 .123 .0 .0 .0 .109 .138 .138 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .082 .125 .0 .0 .0 .109 .140 .140 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .084 .127 .0 .0 .0 .109 .142 .142 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .086 .129 .0 .0 .0 .109 .144 .144 .0 .0 .0 .0 .0 .0 .05 .05 .0
 .066 .088 .131 .0 .0 .0 .109 .146 .146 .0 .0 .0 .0 .0 .0 .05 .05 .0
[((PRG(KS,KD), KD=1,5), KS=1,3)]
 .40 .00 .25 .30 .05
 .30 .00 .35 .30 .05
 .05 .00 .15 .80 .00
[(PPT(K), K=1,4)]
 .096 .800 .089 .015
[(RNS(K), K=1,3), PPRG, PRPM]
 .15 .00 .25 .15 .75
[(BETAP(J), J=0,5)]
56.6096 6.7310 0.0 .000049 .4596 -35.684
[LAGPAY, LAGEND, (LAGX(J), J=1,5)]
0 1 0 0 1 0 0
[(PRNGS(I), PLR(I), POR(I), ANRM(I), COMARA(I), I=1,11)]
 .050667 .057 .01 .545 17725
 .052600 .052 .01 .570 18429
 .054600 .047 .01 .595 18611
 .055000 .043 .01 .620 18701
 .055000 .039 .01 .645 18790
 .055000 .037 .01 .670 18853
 .055000 .034 .01 .695 18915
 .057000 .032 .01 .720 18982
 .059500 .031 .01 .745 19049
 .060000 .030 .01 .770 19059
 .060000 .030 .01 .795 19068
[ANSLOP, ANITCP, JFULAP, JHLFAP]
 .945 .055  6  10
[((XVAR(J), J=1,5), ACRPLT(I), CRPIDL(I), I=1,11)]
26 3.09 290177.0 312.447 0.00 370.00 2562.10
28 3.18 0.00 0.00 0.00 370.00 2562.10
30 3.28 0.00 0.00 0.00 375.00      0.00
30 3.38 0.00 0.00 0.00 380.00      0.00
30 3.48 0.00 0.00 0.00 385.00      0.00
30 3.58 0.00 0.00 0.00 390.00      0.00
30 3.68 0.00 0.00 0.00 395.00      0.00
30 3.78 0.00 0.00 0.00 400.00      0.00
30 3.88 0.00 0.00 0.00 400.00      0.00
30 3.98 0.00 0.00 0.00 400.00      0.00
30 4.08 0.00 0.00 0.00 400.00      0.00
30 4.18 0.00 0.00 0.00 400.00      0.00
[GSINV0, GSMRCH0, PAI0, GPCNT0, AREA0, PINE0,(STAND0(K), K=1,4)]
8804.58 4763.73 784.49 .08909 15059.99 10356.83 3943.69 4765.15
1647.98 4703.16
```

```
[(BFCF(J), J=0,19)]
 .500 1.100 1.700 2.100 2.500 2.835 3.175 3.400 3.675 3.900
4.100 4.210 4.325 4.400 4.410 4.450 4.450 4.400 4.375
[HARDMIN]
3800.0
[LSVOL0, LSMRCH0, AREALS, BFCF0, GCRAT(0), CFACT]
1146.49 599.23 1953.40 2.940 1.394 .28
[end of block 1]
```

Roundwood removals data (unit 2)—In the "stand-alone" version of SPATS, removals data are read from unit 2, in a program segment called TAMMEM. The growth-drain subroutine SPATSGD is called for each year of the simulation, and the removals information read is passed in common block TRAS in the array REMOVE( ). Every 5th year of the simulation, subroutine SPATS is called by SPATSGD, and accumulated removals are passed for each owner and region. Variable names and dimensions are shown in brackets [ ] for explanation. See appendix 3 for a description of variables.

```
[header identifying the data set]
TRIM DATA
[TSTRT, TEND, NNUM]
1980 2030 4
[ REMOVE(N,T), N=1,NNUM, T=TSTRT,TEND ]
     461.824     1318.272      717.442     1192.471    [ 1980 ]
     494.533     1356.485      728.710     1206.584
     509.172     1324.551      769.863     1242.128
     545.086     1356.701      898.611     1327.097
     594.514     1428.603      925.311     1332.999
     623.273     1432.743      895.428     1312.608    [ 1985 ]
        .            .            .            .          .
        .            .            .            .          .
        .            .            .            .          .
    1494.000     1659.000     1503.000     1372.000    [ 2030 ]
```

Brooks, David J. 1987. SPATS: a model for projecting softwood timber inventories in the Southern United States. Res. Pap. PNW-RP-385. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 23 p.

The yield-table projection method for modeling the development of regional timber inventories is outlined, and its application to softwood timber types in the Southern United States is described. Problems of simulating forest management practices and natural succession are discussed. A computer model that projects softwood timber inventories using yield-table projection and stand regeneration using a Markovian probability structure is presented. The methodology and projections of this model are compared with alternative approaches to predicting future timber inventories in this region.

Keywords: Yield-table projection, inventory models, softwood timber supply, South.

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